

EFFECTS OF LONG-DURATION SPACE FLIGHT ON TOE CLEARANCE DURING TREADMILL WALKING

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INTRODUCTION

Upon returning from long-duration space flight, astronauts and cosmonauts must overcome physiologic and sensorimotor changes induced by prolonged exposure to microgravity as they readapt to a gravitational environment. Their compromised balance and coordination lead to an altered and more variable walking pattern (Bloomberg & Mulavara, 2003; McDonald, et al., 1996). Toe trajectory during the swing phase of locomotion has been identified as a precise motor control task (Karst, et al., 1999), thus providing an indication of the coordination of the lower limbs (Winter, 1992). Failure to achieve sufficient toe clearance may put the crew member at a greater risk of tripping and falling, especially if an emergency egress from the vehicle should be necessary upon landing. The purpose of this study was to determine the pre- to post-flight changes in toe clearance in crew members returning from long-duration missions and the recovery thereafter.

METHODS

Ten crew members (mean \pm SD: 46.0 \pm 5.6 yrs) from five missions (duration = 188 \pm 6 days) aboard the International Space Station gave informed, written consent and participated in this study (part of a larger investigation examining the effects of long-duration space flight on the sensorimotor

system). Data collection sessions were performed pre-flight (60-80 days before launch), and six times post-flight (R+, in days after landing): R+1, R+2, R+(3-4), R+(6-7), R+(11-30), and R+(168+).

Subjects wore lab-supplied shoes with footswitches (Motion Lab Systems, Baton Rouge, LA) affixed to the heel and toe areas of the soles. The footswitch data (sampled at 1000 Hz) were used to determine heel strike and toe-off events. Retroreflective markers were affixed to landmarks on the subject to define the head, torso, pelvis and right leg segments. Specifically on the right shoe, markers were placed on the lateral aspect of the calcaneus, the lateral aspect of the 5th metatarsal head, and over the superior aspect of the navicular bone. A six-camera motion capture system (Motion Analysis, Santa Rosa, CA) recorded the three-dimensional positions of the markers at a sampling rate of 60 Hz. The toe was tracked via a virtual toe marker, that was computed to a point at the distal tip of the 2nd toe, at the level of the 5th metatarsal marker (Miller, et al., 2007). The virtual marker indicated the point on the shoe that would most likely contact the walking surface during a stumble or trip.

For each session, subjects performed four 30-sec trials where they walked on a motorized treadmill (Gaitway, Kistler Instrument Corp., Amherst, NY) at 1.8 m/sec (4.0 mph) while performing a dynamic visual acuity task set at

a “far” target distance of 4.0 m (Peters & Bloomberg, 2005). Toe clearance (TCI) was computed for each stride (~30 strides per trial), relative to the virtual toe marker’s height during a static trial recorded before the walking trials. Instead of mean and SD, the median and interquartile range (IQR) of TCI were computed for each trial due to skewness of the data (Begg, et al., 2007). A three-way ANOVA with random effects (subjects) was used to determine significant effects of session and trial on TCI median and IQR ($p < 0.05$). Twelve contrasts of the six post-flight sessions vs. pre-flight and six paired trial combinations were tested for significance with a Bonferroni-corrected p-value of 0.004.

RESULTS AND DISCUSSION

Median TCI showed a nearly significant session effect ($p = 0.052$), however the contrast analysis (Figure 1) indicates a trend of increased median TCI two to four days post-flight, followed by a recovery back to pre-flight values. Surprisingly, median TCI on R+1 was not different than pre-flight.

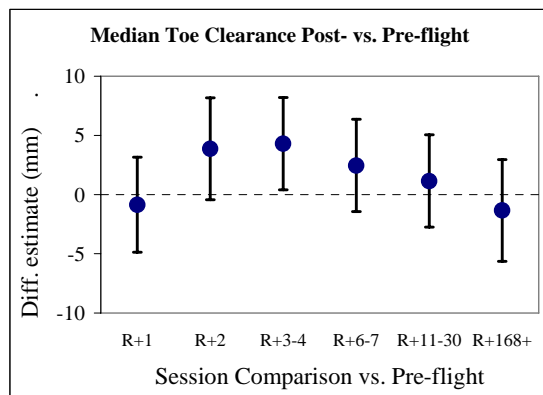


Figure 1. Median TCI difference contrast estimates (Mean \pm 2SE) between post-flight sessions and pre-flight.

Median TCI was significantly affected by trial ($p < 0.001$). All paired comparisons were significant ($p < 0.001$), except for trial 3 vs. 4

($p = 0.01$). Median TCI was greatest for trial 1, then decreased with successive trials.

TCI IQR was also affected by trial ($p < 0.01$), with trial 1 vs. 4 being the only significant paired comparison ($p = 0.002$). While the ANOVA showed that session was not a significant factor on IQR overall ($p = 0.14$), the contrast analysis revealed a significant increase of IQR one day post-flight compared to pre-flight ($p = 0.0039$).

SUMMARY

Crew members returning from long-duration spaceflight walk with an increased variability in toe clearance one day after landing, but return to pre-flight values by post-flight day two, thus reflecting a change in motor control. However from post-flight days two through four, crew members exhibit a slightly increased median toe clearance, possibly indicating that they are giving themselves a "margin for error" during readaptation to the gravity environment.

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